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IV.

NEW OBSERVATIONS
OF
THE PLANET MERCURY.

BY

PERCIVAL LOWELL.

WITH EIGHT PLATES.

Presented May 12, 1897.

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New Observations of the Planet Mercury.

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1. **Observations at Flagstaff.** — In the autumn of 1896 I began observations on Mercury with the 24-inch glass of this Observatory in the hope of detecting the planet's period of rotation. The condition of the air by day exceeded expectation. The telescope had scarcely shown the planet, before attention revealed markings upon its surface, — markings which proved so distinct and permanent as not only to disclose the planet's rotation-period, but to give in its fundamentals definite knowledge of the planet's self. In these observations I was assisted by Mr. D. A. Drew and Miss W. L. Leonard.

2. **Rotation-Period.** — The rotation-period was synchronous with that of the orbital revolution; thus confirming what Schiaparelli, in 1889, had discovered and announced, namely, that the planet turns on its own axis once in the course of its circuit of the Sun. Though the results agreed with Schiaparelli's, their determination was entirely independent.

3. **Observations at Mexico.** — On removing to Mexico I made another series of observations, during January, February, and March of this year. There, again, the day-air proved propitious, and enabled us to confirm and extend the results obtained at Flagstaff.

4. **Method of Observation.** — Before entering upon an account of them I shall give in a word or two what is important, the method by which they were secured; since the success of the observations is due to principles which this Observatory has been investigating, the importance of which is not yet generally understood.

First. The result was not due to what most observers still consider the essentials of observation, a large aperture or keenness of vision. This I state after experience with apertures ranging from 4 to 24 inches, and after comparison of the powers of many different eyes. At times a small aperture is better than a large one, at other times not, the relative efficiency of the glass depending upon the condition of the air. In Mexico I was able to test this very effectively by having the 6-inch clamped on to the 24-inch tube, so that it shared the advantages of the other's mechanism, and, what is as vital in such a test, it enabled the two images to be compared almost at the same instant by the same eye. I found that the performance of the 6-inch was nearly equal to that of the 24-inch; that on the average it revealed almost as many markings as the larger glass; and that when the two differed in efficiency it was apparently question of the kind of air-waves prevailing at the moment. In the moments of best seeing, the 24-inch of course distanced its competitor; but the detection of the principal markings does not demand superiority of the sort.

Secondly. Between fairly normal eyes there is practically no such thing as superior keenness of vision. After a little practice in the subject one eye proved as good as another. Not keenness of sight, but keenness of brain, distinguishes the good from the poor observer. It is with astronomical observation exactly as it is with every-day affairs. The able observer is he who perceives what any one may see.

Due neither to aperture nor eye, we come now to what it was due, to wit, to the air of the Observatory site, backed by persistence in the observer: (1) the air must be as steady[1] — not as clear — as possible; (2) the observer must study his subject. To see the markings it is necessary, for an unpractised eye, that the air should be steady enough to show the disk clear-cut. Although I have been able to detect the markings unmistakably in air such that I could not see the contours of the disk, such air would not suffice to show them to one not versed in the subject. The above criterion is sufficiently exact to begin on; later, the observer will discover that sharpness of limb and appearance of detail depend upon special and different atmospheric conditions, and do not always go together.

With regard to the second point, the best results are got by looking for the planet at times not usually thought practicable. First, the planet must be scanned by day exclusively, and as near high noon as possible. Secondly, the planet can and should be followed almost up to superior conjunction. The best time to study him is when planetary almanacs state, "Mercury invisible during the month."

In the next place, although the size of the object-glass used is largely immaterial, the power of the eyepiece is not. High powers will show nothing. I had eyepieces specially made for me; even the lowest used on large telescopes proving too high.

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[1] For what constitutes steadiness I refer the reader to a preliminary monograph by Mr. Douglass, to whom is due the detection and study of its cause, in Popular Astronomy for June, 1897.

Those magnifying from 135 to 170 diameters turned out the best on the 24-inch; on the 6-inch, from 75 to 135. With 300 on the 24-inch, if the air was good, the markings still showed fairly well.

In place of low powers, diaphragming the emergent pencil — a device of Mr. Douglass — sharpens the detail. Both processes have interesting physiological bearings.

Lastly comes persistence. No air is continuously good. It has good moments and bad. The good must be patiently waited for and seized. What applies to a single sight applies *a fortiori* to acquisition of any full knowledge of the planet; and a little persistent practice will bring a great surprise, greater than the surprise of seeing it all, — the surprise that it was not all seen before.

5. **Method of Measurement.** — The mode of taking the measures also deserves a word. My measures were made with a filar micrometer, the thread being placed, not on, but near, the edges of the disk, without and within respectively. This method has great advantages over any attempt to place the thread on the limb; in fact, to place the thread on the limb accurately is impossible, first, because of the excessive irradiation produced by so doing, and secondly, because the eye is unable to see well both thread and limb at the same time.

For accuracy the filar micrometer is to be preferred to the double image micrometer. There is prevalent a curious mistake about the latter, to the effect that it eliminates irradiation. That this is not possible is easily shown by considering that contrast alone causes irradiation, and that the contrast in the case is always between the disk and the sky. The error seems to have arisen from supposing the irradiation to be due to contrast between the two disks made by the eyepiece, which of course is not the case. The only reduction of irradiation in the double image micrometer comes from the somewhat fainter images it gives, an effect which is easily produced with the filar micrometer by slightly reducing the light with an interposed glass. Thus the double image micrometer possesses on this account no advantage over the filar micrometer. On the other hand, it possesses very distinct disadvantages, for the images formed by the double eyepiece are subject to greater distortion and flare, — a distortion which renders the measures less reliable.

6. **Two Classes of Observations.**— The observations themselves consisted of two classes: (1) drawings of the planet's surface features; (2) micrometric measures of the planet's diameters and discussion of the same.

7. **Drawings.** — We will take up the drawings first. 311 drawings and 12 sketches were made of the planet's disk. Of these, 104 drawings and 5 sketches were made

at Flagstaff, and 207 drawings and 7 sketches at Mexico. In all of the drawings, markings appear depicted on the planet's surface. These markings were seen and drawn by every member of the Observatory, six observers in all, and through two different telescopes, the 24-inch and the 6-inch.

8. **Phase of Observation.** — The planet was watched from as slender a crescent as it was possible to pick up to almost a full disk. Near inferior conjunction it is difficult to find the planet, the greater angular diameter of the disk being more than offset by the phase and the fainter illumination of the surface shown. Near superior conjunction, on the other hand, the detection of the planet is much easier than one would suppose. In Mexico I observed it to within 4° of right ascension of the Sun, and only stopped there because of removing the observatory to Flagstaff. All that is necessary to render it readily visible is to screen the object-glass as much as possible from the direct rays of the Sun.

9. **Period of Rotation not Short.** — As the markings thus revealed proved : (1) distinct ; (2) permanent ; and as the drawings, in all 311 of which they appear, were made at intervals of time ranging from a few minutes to many months apart, the rotation period of the planet was patent, and with it the position of the axis of rotation.

They showed that the planet rotates (1) in a period synchronous with its orbital revolution ; (2) round an axis substantially perpendicular to the plane of its orbit. To make this evident at a glance I have, in Plates XXX. and XXXI., reproduced two sets of three triads of drawings each, the one set by Miss Leonard, the other by me.

It will be seen that there is no perceptible shift in the positions of the markings in any of the several six triads. Yet the intervals between the drawings in Plate XXX. are : —

	h.		h.
Between 1 and 2	0.7	Between 5 and 6	2.2
" 2 " 3	3.1	" 7 " 8	3.9
" 3 " 4	20.1	" 8 " 9	0.6
" 4 " 5	1.2		

	h.
Or between the extremes of row 1, an interval of	3.8
" " " " 2, " "	3.4
" " " rows 1 and 2, an interval of	27.2
and between the extremes of row 3, " "	4.5

Similarly in Plate XXXI. we have : —

	h.		h.
Between 1 and 2	0.7	Between 5 and 6	2.0
" 2 " 3	5.0	" 6 " 7	68.1
" 3 " 4	65.3	" 7 " 8	1.4
" 4 " 5	3.4	" 8 " 9	21.5

Or taken in rows, there is between the extremes of row 1 an interval of $5^h.7$; of row 2, an interval of $5^h.4$; of row 3, an interval of $22^h.9$.

We have then in these drawings nearly all manner of intervals, from 0.6 of an hour to several days; and all without the slightest effect upon the positions, except for a slight recession from the terminator presently to be explained.

That more markings were seen at one time than at another is simply a question of the steadiness of our own air. For example, the air happened to be much steadier in Figs. 5 to 9 of Plate XXXI. than it was in Figs. 1 to 4.

The October and November drawings are among the Flagstaff ones, the January among the Mexican, and as Flagstaff time is 7 h. west of Greenwich, and Tacubaya, Mexico, $6^h.6$ west, it will be seen that these drawings were made all the way from about nine o'clock in the morning to four in the afternoon. From them it is evident that any short period of rotation is negatived; while if the positions of the markings be measured, it will be found that they all harmonize with a period synchronous with the orbital revolution.

10. **Libration.** — To prove now that such is the rotation-period: if we take all the drawings and measure in them the distance of any given marking from the terminator, we find, on reduction, this distance to be invariable, and invariability is a corollary of such synchronousness. To show this result, we must first consider an interesting detail of the planet's rotation disclosed by the markings simultaneously with that rotation itself, — the libration in longitude due to the eccentricity of the planet's orbit, since this enters as a correction into the reduction.

As the rotation of the planet must be uniform, due to the great moment of its rotary momentum, while the angular velocity of revolution of a body moving in an ellipse is not, there must be produced, in the case of isochronism of rotational and orbital periods for such an orbit, a libration of the markings in longitude.

To determine it we have: that the mean angular velocity of revolution in the ellipse is the angular velocity of a body supposed to be describing a circle in the time occupied by the planet in the ellipse. For the area of the ellipse being $\pi\, a b$, and the period T, the areal velocity in the ellipse, which is constant, is $\frac{\pi\, a b}{T}$. This is the areal velocity in a circle of radius $\sqrt{a b}$ supposed described in the same time.

To find, therefore, the point on the ellipse where the radius has the value corresponding to the mean angular velocity, we must take the expression for r of the ellipse referred to its focus as a pole,

$$r = \frac{a\,(1 - e^2)}{1 + e \cos v},$$

and equate it to that of the circle supposed described about that focus with the length of radius $\sqrt{a\,b}$. This geometrically is the point of intersection of the two curves, since the value of r is common to both.

Consequently for the point sought

$$\sqrt{a b} = \frac{\sqrt{a}\,(1 - e^2)}{1 + e \cos v}.$$

Since a may be taken as unity, this is

$$\sqrt{b} = \frac{(1 - e^2)}{1 + e \cos v},$$

$$\text{or } \cos v = \frac{1 - e^2 - b^{\frac{1}{2}}}{e \,.\, b^{\frac{1}{2}}};$$

or since

$$b = \sqrt{1 - e^2}, \qquad \cos v = \frac{1 - e^2 - (1 - e^2)^{\frac{1}{4}}}{e \,.\, (1 - e^2)^{\frac{1}{4}}} = \frac{(1 - e^2)^{\frac{3}{4}} - 1}{e}.$$

In the case of Mercury, $e = .205605$; v, the true anomaly of the point of maximum libration is therefore 98° 55′.13.

But $\frac{a - r}{a\,e} = \cos u$, where u is the eccentric anomaly; and $u - e \sin u = \zeta$, where ζ is the mean anomaly; whence $v - \zeta$, which is the amount of the maximum libration, is 23° 40′ 38″.

As the period of the planet is 87.96926 days, the mean angular velocity of revolution, which in the case of Mercury is also the angular velocity of rotation, is 4°.092 a day; the angular orbital velocity at perihelion, 6°.346 a day; and the angular orbital velocity at aphelion, 2°.755 a day.

Consequently the daily gain of the angular orbital over the angular axial velocity — or the daily increase of libration east or of decrease west — at perihelion is 2°.254; similarly the loss at aphelion is 1°.337.

The time taken by the planet from perihelion, where the libration is nothing, to the point of maximum libration, is 18 days, 9.28 hours, and from this point to aphelion 25 days, 14.35 hours.

As the planet's heliocentric longitude at perihelion is now 75° 51′, the heliocentric longitude of the points of maximum libration are 174° 46′ and 336° 56′, while at 75° 51′ and 255° 51′ the libration is nothing.

Calculating the libration, together with the phase angle for February and March, 1897, — as this will be the most useful to us later on in the paper, — we get

TABLE I.

PHASE ANGLE AND ANGLE OF LIBRATION.

Greenwich Mean Noon. Date.	Phase Angle. ι	Angle of Libration. ω	Greenwich Mean Noon. Date.	Phase Angle. ι	Angle of Libration. ω
Feb. 4	109°.8	−23°.3	Mar. 3	55°.0	+4°.9
" 5	106.2	23.0	" 4	53.7	6.2
" 6	102.9	22.6	" 5	52.3	7.5
" 7	99.7	22.1	" 6	51.0	8.8
" 8	96.8	21.5	" 7	49.7	10.1
" 9	94.0	20.8	" 8	48.4	11.3
" 10	91.4	20.0	" 9	47.1	12.5
" 11	88.9	19.2	" 10	45.7	13.6
" 12	86.5	18.3	" 11	44.4	14.7
" 13	84.2	17.4	" 12	43.0	15.8
" 14	82.0	16.4	" 13	41.6	16.9
" 15	79.9	15.4	" 14	40.2	17.9
" 16	78.0	14.3	" 15	38.7	18.8
" 17	76.1	13.1	" 16	37.2	19.7
" 18	74.3	11.9	" 17	35.6	20.5
" 19	72.6	10.7	" 18	34.0	21.2
" 20	70.9	9.5	" 19	32.3	21.8
" 21	69.2	8.3	" 20	30.5	22.4
" 22	67.6	7.0	" 21	28.7	22.9
" 23	66.1	5.7	" 22	26.8	23.3
" 24	64.6	4.4	" 23	24.8	23.5
" 25	63.1	3.1	" 24	22.7	23.7
" 26	61.7	1.7	" 25	20.6	23.7
" 27	60.3	−0.3	" 26	18.5	23.7
" 28	59.0	+1.0	" 27	16.2	23.5
Mar. 1	57.6	2.3	" 28	13.9	23.2
" 2	56.3	3.6			

MAXIMA AND MINIMA BETWEEN SEPTEMBER, 1896, AND MARCH, 1897, WASHINGTON MEAN TIME.

In Aphelion ; Libration nil .	Sept. 4	5 hours	
At Greatest Libration W. .	Sept. 29	20 "	23°.677
In Perihelion ; Libration nil .	Oct. 18	5 "	
At Greatest Libration E. . .	Nov. 5	14 "	23°.677
In Aphelion ; Libration nil .	Dec. 1	4 "	
At Greatest Libration W. .	Dec. 26	18 "	23°.677
In Perihelion ; Libration nil .	Jan. 14	4 "	
At Greatest Libration E. . .	Feb. 1	13 "	23°.677
In Aphelion ; Libration nil .	Feb. 27	3 "	
At Greatest Libration W. .	Mar. 24	17 "	23°.677

11. **Proof of Long Period of Rotation.** — On measuring the position of Testudo regio in the drawings, we find for its longitude the following results : —

TABLE II.

LONGITUDE OF TESTUDO REGIO,* 1896.

Date.	Mountain Standard Time.	Longitude Centre of Disk. Corrected for Libration.	Longitude of Centre of Testudo regio from Centre of Disk.		Resulting Longitude of Testudo regio.
			Uncorrected.	Corrected for Phase.	
	h. m.	°	°	°	°
Oct. 28	2 53	278	2	4	276
	20 31	281	5	4	276
	22 49–57	281	7	4	274
	23 46–59	281	7	4	274
Oct. 29	2 5–12	281	14	4	269
	22 12	283	12	4	271
	22 20	283	16	4	267
	22 38	283	10	4	273
	23 0	283	12	4	271
Oct. 30	4 2	284	12	4	272
	20 40–50	286	14	4	272
" 31	23 18–32	288	16	4	272
	23 41	288	14	4	274
Nov. 1	0 13	288	3	4	285†
	21 16	291	22	4	269
" 2	0 38–45	291	19	4	272
	2 40	291	17	4	274
" 4	1 57– 2 3	296	32	4	264
	22 50	299	35	4	264
" 5	0 11–19	299	37	4	262
	21 39–46	301	37	4	264
	22 25–32	301	37	4	264
" 6	22 13	303	39	4	264
	22 49	303	33	4	270
" 8	22 54– 23 8	308	39	4	269
Mean					270
Corrected for difference between theoretic and visible phase .					4
					274

During this period the planet revolved through 54° of its orbit.

The slight difference between these values and those published in the Astronomishe Nachrichten by the writer is due to remeasurement of the original drawings, those in the former article having been made from the published copies.

Between the first of the above set of longitudes and the last of those in the following table, the planet made one complete circuit of the Sun and 91° of another.

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* Called in previous papers Argi regio.

† This drawing is evidently poor for position of terminator.

TABLE III.

LONGITUDE OF TESTUDO-REGIO, 1897.

Date.	Mexico Time (6h. 36m. west of Greenwich Mean Time).	Longitude of Centre of Disk.	Longitude of Centre of Testudo regio from Centre of Disk.		Resulting Longitude of Testudo regio.		
			Uncorrected.	Corrected for Phase. See Table VI.			
	h. m.						
Feb. 7	23.5	242°	19°	28°	261°	270°	272°
“ “	23.8						
“ “	23.9						
“ 8	0.3	246	15	24	261	270	
“ “	21.8						
“ “	22.4						
“ 9	1.7	256	6	13	262	269	
“ “	1.8						
“ 11	21.8	259	5	12	264	271	
“ “	22.1						
“ “	1.5						
“ “	2.5						
“ 12	21.7	262	3	11	265	273	
“ “	22.0						
“ “	22.3						
“ “	22.7						
“ “	23.0						
“ “	1.1						
“ 13	23.6						
“ 14	0.6	265	3	10	268	275	
“ “	21.5						
“ “	21.8						
“ 15	22.4	268	–1	6	267	274	

From the above, then, we see that the period of rotation is isochronous with the period of orbital revolution.

As the chances that a mass detached from the primal nebula should rotate in the time of its orbital revolution, even under the conditions most favorable to such an event, are but one in infinity, we see that such isochronism must be an after-result to its original giving off. Now the only force capable, so far as we know, of bringing this about is tidal friction. In Mercury, then, we have before us the first planetary instance of tidal action.

12. **Axis of Rotation.** — That the axis of rotation is practically perpendicular to the plane of the orbit is shown by the fact that the movement of the markings due to libration is perpendicular to the terminator. No deviation from perpendicularity was at any time apparent.

Furthermore, the slight shift of the markings north and south, due to the heliocentric latitude of the planet at different times, was apparently discernible. If the drawings made in October and November, 1896, be compared with those made of the same part of the planet in February and March, 1897, it appears that the markings came a trifle farther north in the latter case. Now in October and November, 1896, the heliocentric latitude of the planet attained its southern limit, while in February and March, 1897, it similarly reached its northern one. Taking the planet's distance from the Earth at the time into account, the effect would be a shift of some four degrees in all. This would imply that a deviation of four degrees from perpendicularity in the axis of rotation should have been observable did it exist.

13. **Markings.** — In their characteristics the markings on the planet's surface are both unique and suggestive. The markings are: (1) unlike those on any other planet, coming nearest in appearance to those on Venus, but not resembling them to any extent; (2) long and narrow, of the nature of lines, not patches; (3) among the darkest of planetary markings; (4) although linear, not of uniform width; (5) given to appearing as a succession of dark dots, like beads on a chain; (6) darkest at points where they cross, giving rise to spots at the intersections; and (7) singularly symmetrically placed.

To prevent misconception, I may add that neither the lines nor the spots show any of that startling regularity observable in the "canals" and oases of Mars. Unlike the markings on Mars, they do not suggest artificiality.

The widest of the lines, Testudo regio, is about 4° (of longitude on the planet) wide. Most of the others are from a third to a half of this width. Such is the normal size, if one may use the expression; for Testudo regio is in many respects *sui generis*. It is worth noting that familiarity decreased the width and increased the number of the lines. (See Plates XXVIII. and XXXIV.)

The spots are not much broader than the lines, of which in many cases they seem to be but the darker portions. There have been seen nineteen of these spots at the places where lines cross. Akin to them apparently are the beads into which a line occasionally appears to break up.

In the matter of the fineness of the lines — which only in poor air look like diffuse streaks — it is interesting to note that Schiaparelli (Astronomische Nachrichten, No. 2944), with his usual ability, suspected just what has turned out to be the fact, that the markings are a mass of fine lines which he was not able to see definitely as such. His paper I read after my own observations were made.

14. **Symmetrical Arrangement.** — On plotting all the markings, 78 in number, there stood revealed a very curious symmetry in their arrangement. This symmetry showed itself first as regards the north and south portions of the illuminated disk, and then as regards the east and west sides of the same. It becomes the more noticeable on considering them in detail.

Testudo regio. — Perhaps the most conspicuous markings on the planet are two bands cutting off the two poles respectively and about 33° distant from them. Such is the appearance they present when the planet is morning star and the libration to the westward of the mean. As the libration swings east, bringing these markings inboard, the two cut-offs begin to turn toward each other, approach, and then suddenly meet to form one long marking running north and south. To an observer noting this change of intention for the first time, the effect is striking. For beyond the band lies white disk, all the way up and down. But unexpected and startling as the effect is, the fact of it becomes no less so when calculation shows this band to lie on the meridian of mean libration.

The band I have called Testudo regio. It is the most important marking on the eastern side of the planet, — the orientation is to one standing on the planet with his face to the south, — and is, as I have said, four degrees of Mercurian longitude broad, that is, about 120 of our miles. Once in a moment of exceptional seeing I had the good fortune to see it perfectly contoured; that is, the edges were sharply differentiated from their surroundings.

Next in salience are lines running across the disk along what the position of the axis shows to be parallels of latitude. One of these lies almost upon the equator, while others cross at diverse distances north and south of it. The list of those so far detected is as follows: —

About 41° south.
29° "
17° "
6° "
1° north.
9° "
20° "

Besides these are others not definitely enough recognized to be mapped.

Next comes a set of lines running apparently on the meridians; of which the three most salient ones are situated in about longitude 335°, 0°, and 28° respectively. They run, so far as I have been able to determine, due north and south, and practically stretch from pole to pole.

Crossing these two sets at angles of about 38° are two other sets of transverse ones, in a general way 30° apart and in nearly equal numbers on opposite sides of the zero meridian, some six or seven running northwest and southeast across the disk, and about the same number running northeast and southwest.

It might seem to be supererogatory to point out that this symmetry is on the planet, not elsewhere, as the lines that cause the symmetry turn with the planet.

Before considering what this singular arrangement may betoken, certain other features of the disk are to be noted.

15. **No Clouds.**— The markings always show when their particular part of the planet is turned toward us, unless our own atmosphere at the moment be too bad. This invariable visibility of the markings is the first point to be remarked. For it shows that nothing near the surface of Mercury hides that surface from view. In other words, no clouds or mists or fog float between us and it. The surface lies bare to our gaze.

16. **Surface Colorless.**— Next, that surface is colorless, the markings standing out in dark relief against the otherwise uniform pale white. Unlike Mars, with his beautiful opal-like tints, — rose-ochre and blue-green, — unlike the hues of the Earth seen from afar, — unlike even Venus, with her straw-colored veil, — Mercury shows a face as ashen as the Moon, a chiaroscuro in black and white.

17. **No Change.** — No change ever sweeps over this face. The markings look at one time, apparently, just as they do at another.

18. **No Polar Caps.** — There is no sign of white in the neighborhood of the poles.

19. **Atmosphere.** — None of the effects which would follow upon the presence of an atmosphere are discernible; nor were any evident during the observations at this Observatory when the planet crossed the Sun's face in November, 1894. If there be an atmosphere, it is thin.

20. **Surface Physical Characteristics.** — From these observations stand disclosed the following physical features of the planet's surface ; (1) that nothing veils it in the way of clouds; (2) that it holds no appreciable atmospheric envelope : (3) that it has no polar snows; (4) that it contains no bodies of water; (5) that it supports no vegetation; (6) that no change takes place upon it; and that, in short, it is a dead world. The first point is proved by the continuous visibility of the markings; the second, negatively by what I have stated above, and positively by the albedo of the disk and the loss on the terminator shown by micrometer measures of the diameters; the third, by the absence of white at the poles; the fourth and fifth, by the entire

absence of both change and color anywhere; and the sixth, by the immutability of the whole.

All these characteristics are just what the rotation period and the kinetic theory of gases would lead us to infer as probable upon a globe of Mercury's size rotating as he does. Observation thus corroborates inference.

Two further points are worth noting, the one the brightness along the limb, the other the shadings at the cusps.

21. **Brightness along Limb.** — From some time before to some time after the moment of dichotomy the limb is noticeably brighter than any other part of the disk. The brilliancy is almost invariably confined to a bright line or a narrow lune; and what is curious, it is not always in the centre of the limb, but on occasions is conspicuous along its southwestern edge while being absent from its middle. I have noted this peculiar position of the illumination at recurrent elongations, although chronicling it but once. My written notes are as follows: —

Sept. 2, '96,	limb brightest part of planet;
14,	limb bright all round like Moon.

At another elongation: —

Oct. 16, '96,	limb much brighter than rest of disk;
18,	limb, especially S, the brightest part of the disk;
20,	planet's disk brightest a little in from limb N.

And at yet another: —

Feb. 6, '97,	limb brighter than rest of planet;
7,	bright along limb, brightness in a line along limb;
9,	disk brightest along central portion of limb;
23,	very bright along limb;
Mar. 2,	bright along limb.

22. **Shadings at the Cusps.** — At one or both of the cusps is frequently visible a shading, especially when the phase is a crescent. This is not, seemingly, a part of the failure to see the cusps, although it may be due to such cause, but apparently is produced by a shading within their contour. The effect may last until the planet is fairly gibbous. See Figs. 1, 2, 3, 4, 5, 6, 8, 9, Plate XXX.; Figs. 1, 2, 3, Plate XXXI.; and Figs. 1, 2, 3, 4, Plate XXXII.

23. **Albedo.** — The look of the planet shows its albedo to be low. For while the markings are more contrasted with their surroundings than is the case with Venus, — with which body it is best to compare Mercury, — the general reflective power of the planet's surface is much less. This appeared *passim* in the course of the observa-

tions. At the time the observations began the planet was between superior conjunction and eastern elongation, and lay at the time very conveniently placed for comparison with Venus, the two planets being near each other, Mercury lying at first at a somewhat greater angular distance from the Sun, and then at a slightly less, Venus passing out and Mercury in on September 24. The difference in the albedo or intrinsic brightness of the surface of the two bodies was most marked. My initial note on Mercury, on August 21, reads: "Mercury, — strikingly not so bright in albedo as Venus; just looked at on a brighter sky, too." At this time Mercury was nearer the Sun in the proportion of 100 to 165, and therefore his surface was 2.73 times more brilliantly illuminated than hers. But the relative lustre of the two was even more disproportionate the other way. This relative appearance continued to be presented on every occasion, only with ever increasing contrast. For as Mercury's phase increased, his surface lost visibly in lustre; that is, quite apart from the loss in area as a whole, what illuminated surface remained showed much less bright, square unit for square unit, than it had when the disk was nearer the full. A similar loss of albedo with increase of phase is shown by our Moon.

In consequence of this loss with increase of phase, the disproportion between Venus and Mercury is not quite so great as appeared on August 21, inasmuch as Venus at that time was the nearer to the full.

On the other hand, I have compared Mercury with the Moon and found his surface the brighter of the two in about the proportion that his greater proximity to the Sun would cause. He thus shows as an airless body should.

24. **Explanation of the Map.** — From the markings detected at Flagstaff and in Mexico is constructed the map of the planet in Plate XXVII. The face the planet shows us suggested the projection to be used, — parallel projection for the latitudes and an equidistant one for the longitudes. For since the axis of rotation is substantially perpendicular to the Earth's orbit, the latitudes are seen forever foreshortened in parallel projection, while the longitudes are all of them at one time or another seen as they are.

To either side of the hemisphere of mean libration I have added wings on the same projection for such further longitudes as the libration reveals.

The longitude of the centre of the disk when at its mean libration is taken as the zero meridian.

25. **Signification of the Symmetry of the Markings.** — From all of the foregoing we see that Mercury is a dead body, like our own Moon. Was it always so or not is the next question. With regard to this, the curious symmetry observed in the

position of the markings has something to say. And in this connection it is distinctly to be noted that, though in a general way symmetric, the two sides are by no means the same. The markings are suggestively bilateral without being like. Now when we take three facts into account: (1) the symmetry north and south; (2) the symmetry east and west; (3) the relation of Testudo regio to the line of mean libration; — we have pretty clearly hinted that the planet has turned the same face to the Sun from before such time as the markings were made; and that the markings are due to some cause which has since operated upon this face to the exclusion of the other. This cause can be none other than the heat received from the Sun. The continuous hiding of one hemisphere from the Sun's rays would cause a greater contraction in it than in the other in the days when the cooling was going on, and this unequal cooling of one side would result in cracks, — cracks which we now see stereotyped in the markings. This explanation, which has been suggested to me, seems the most probable one to adopt. Besides accounting for the general symmetry of the markings, it explains in addition why they should be lines rather than patches.

26. **Genesis of Isochronism.** — We perceive, also, that this theory of their genesis agrees with what we should expect to find. For the present practically airless condition of Mercury must have resulted very early in its career as a body separate from the primal nebula. In consequence there can since then have been neither air nor water upon the planet, — none of the wherewith to cause tides to break its rotation. The slowing up must therefore have been brought about by substantial tides, — tides, that is, of the whole body, — and therefore have taken place before the planet had solidified. Consequently when the planet was solidifying it was already presenting the same face in perpetuity to the Sun, from which cracking would inevitably result. We conclude, then, that Mercury is not only a dead world now, but that it has never been anything else.

27. **Surface Visible.** — From the rotation period and the libration it appears that we see at one time or another five eighths of the planet's surface, and that the other three eighths remain forever hidden from view because forever unilluminated.

28. **Measures of the Planet's Diameters.** — Between the 2d of September, 1896, and the end of March, 1897, I made 109 sets of measures of the planet's diameters. These were taken through the phase axis and the diameter perpendicular to it. Each set consisted of three double diameters. The sets were nearly all complete. The mean of each set was then expressed in seconds of arc, corrected as in the tables, especially for irradiation, reduced to distance unity, and tabulated. The results for the polar measures are given in Table IV.; those for the equatorial in Table V.

As the markings showed that the planet's polar axis was substantially perpendicular to the plane of its orbit, these phase polar and phase equatorial diameters practically coincided with the true ones.

29. **Correction for Threads.** — The correction for the threads, owing to the way the diameters were taken, is a very small quantity and is massed with that for the spurious disk. The correction for the micrometer thread and the spurious disk is taken at 0″.20 for the old micrometer; at 0″.10 for the new micrometer in January; and at 0″.07 for the new micrometer in February and March.

30. **Correction for Irradiation.** — A word upon the correction for irradiation is necessary. In all planetary measures the correction for irradiation is of fundamental importance, in spite of which it is usually either not applied at all, or applied *en bloc* to the final result. Determinations are obtained ignoring it, which in consequence are quite worthless. To show the magnitude of the error thus committed, I may take the expression for the polar compression say of Mars $\frac{a-b}{a}$, with a and b nearly equal. If the correction for irradiation, as frequently happens in consequence of phase, be a third as great again on b as on a, while on either it is two or three times as great as the difference between them, it is evident that by ignoring it the value obtained for the ellipticity is vitiated nearly one hundred per cent.

The correction for irradiation I got from intercomparison of measures made upon a painted disk, upon Mars, Venus, and Mercury, and from estimates made upon the old moon in the new moon's arms, taking in all these cases relative albedos, eyepieces, object-glass, and sky illumination into account. That the resulting correction is not far from the truth seems to be indicated by the fact that the diameters thus got for Venus and Mars agree closely with the best previous determinations; the polar diameter of Venus, at distance unity, coming out 16″.96, and that of Mars 9″.32.

For the polar diameter, the correction for the irradiation is taken at 0″.07 at the beginning of the time, and thence graded to 0″.20 at the end, because of the constantly increasing illumination at the cusps.

TABLE IV.

POLAR DIAMETERS OF MERCURY, 1897.

Date.	G. M. T. Hour.	Uncor.	Cor. for Mic. Th. and for Spu. Disk.	Cor. for Irr.	Reduced to Dist. Unity.
Jan. 6	11.3	6.97	6.87	6.80	6.64
Feb. 9	5.4	8.06	7.99	7.92	6.87
“ 13	6.2	8.07	8.00	7.93	7.41
“ 15*	5.8	7.61	7.41	7.34	7.10
“ 18	6.9	6.26	6.19		
“ 19	6.3	6.53	6.46		
“ 20	5.6	6.39	6.32		
“ 21	5.7	6.35	6.28		
“ 22	4.1	6.84	6.77	6.68	7.15
“ “	5.2	6.04	5.97		
“ 23	5.3	6.23	6.16		
“ 24	4.2	6.41	6.34	6.23	6.84
“ “	5.2	5.78	5.71		
“ 25*	3.7	6.56	6.36	6.25	6.94
“ 26	4.3	6.07	6.00	5.88	6.61
“ “	5.4	6.14	6.07	5.95	6.69
“ 28	3.9	6.53	6.46	6.34	7.29
“ “	4.4	6.46	6.39	6.27	7.21
“ “	4.6	6.64	6.57	6.45	7.42
Mar. 1	3.1	6.21	6.14	6.02	6.99
“ “	3.3	6.18	6.11	5.99	6.95
“ “	4.0	6.41	6.34	6.22	7.22
“ “	4.4	6.40	6.33	6.21	7.21
“ 2*	3.4	6.59	6.39	6.27	7.35
“ “	3.9	6.54	6.34	6.22	7.30
“ “	4.3	6.41	6.21	6.09	7.15
“ 3*	3.7	6.81	6.61	6.49	7.69
“ “	4.0	6.47	6.27	6.15	7.28
“ “	4.7	6.14	5.94	5.82	6.90
“ 4	3.7	6.14	6.07	5.94	7.10
“ “	4.6	6.12	6.05	5.92	7.08
“ 5	3.3	5.99	5.92	5.79	6.98
“ 6	4.7	6.22	6.15	6.02	7.33
“ “	5.2	6.17	6.10	5.97	7.27
“ 8	3.4	5.80	5.73	5.58	6.90
“ “	4.6	6.08	6.01	5.86	7.25
“ 9	3.4	6.03	5.96	5.81	7.24
“ “	3.8	6.05	5.98	5.83	7.27
“ 10	2.9	5.84	5.77	5.62	7.06
“ “	3.8	6.09	6.02	5.87	7.37
“ “	4.0	6.00	5.93	5.78	7.26
“ 11	3.1	6.03	5.96	5.80	7.34
“ 12	3.5	5.97	5.90	5.74	7.31
“ 15	3.9	5.70	5.63	5.46	7.08
“ “	3.9	5.79	5.72	5.55	7.20
“ “	4.4	5.77	5.70	5.53	7.17
“ 17	3.2	5.63	5.56	5.39	7.07
“ “	3.8	5.58	5.51	5.34	7.00
“ 19	4.2	6.02	5.95	5.76	7.62
“ 20	4.6	6.04	5.97	5.78	7.68
“ 21	3.9	5.81	5.74	5.54	7.39
“ 23	4.1	5.81	5.74	5.54	7.43
“ 26	4.2	5.76	5.69	5.49	7.40

* Measures on these dates made with old micrometer; all others with new one.

TABLE V.

EQUATORIAL DIAMETERS OF MERCURY, 1897.

Date.	G. M. T. Hour.	Uncor. Irr.	Cor. Mic. Th.	Cor. Irr.	Reduced to Dist. Unity.
		″	″	″	″
Jan. 6	11.3	4.06	3.96	3.83	3.74
Feb. 9	7.0	3.60	3.53	3.40	2.95
“ 13	6.7	4.28	4.21	4.08	3.81
“ 19	6.8	4.13	4.06	3.93	4.04
“ 20	6.2	4.12	4.05	3.92	4.09
“ 21	6.0	4.36	4.29	4.16	4.40
“ 22	4.7	4.11	4.04	3.91	4.19
“ 23	6.1	4.22	4.15	4.02	4.37
“ 24	4.7	4.04	3.97	3.84	4.22
“ 28	4.2	4.11	4.04	3.91	4.49
Mar. 1	3.6	4.01	3.94	3.81	4.42
“ 4	4.0	4.10	4.03	3.90	4.66
“ “	4.2	4.20	4.13	4.00	4.78
“ 5	3.5	4.21	4.14	4.01	4.84
“ 6	5.5	4.34	4.27	4.14	5.04
“ 8	3.7	4.41	4.34	4.21	5.21
“ “	4.4	4.50	4.43	4.30	5.32
“ 9	3.7	4.35	4.28	4.15	5.17
“ “	4.6	4.57	4.50	4.37	5.45
“ 10	3.1	4.32	4.25	4.12	5.17
“ “	3.4	4.43	4.36	4.23	5.31
“ 11	3.6	4.41	4.34	4.21	5.33
“ 17	3.5	4.43	4.36	4.23	5.55
“ 19	4.5	4.98	4.91	4.78	6.33
“ 20	4.8	5.05	4.98	4.85	6.44
“ 23	4.4	4.99	4.92	4.79	6.43
“ “	4.9	5.07	5.00	4.87	6.53
“ 26	4.6	5.32	5.25	5.12	6.90

The correction for irradiation was taken at $0''.13$ throughout.

31. **Measures of Drawings.** — Besides tabulating the measures, I have measured the phases of the drawings and tabulated them in Table VI., the phase entered for any day being the mean of the values for that day. The ratio of the visible polar and equatorial diameters is given first; then the phase angle to which this corresponds; and, lastly, the difference between this phase angle and the theoretic phase at the time. Besides these for comparison are placed the phase ratios, angles, and difference got from the measures corrected for the micrometer threads, but not corrected for irradiation; in other words, such as they appeared to the eye.

TABLE VI.

1897. Date. G. M. N.		Phase Angle Theoretic.	Drawings: Ratio Equat. to Polar Diameters.	Phase Angle of Drawings.		Diff. between Theoretic and Drawn Phase.	Mic. Meas. Ratio Equat. to Polar Diams. both cor. for Threads only, and Polars graded from 6″.38 to 7″.69.	Phase Angle of Micrometric Measures.	Diff. between Theoretic and Measured Phase.		Remarks.
Jan.	4	73°.3	.553	83°.9		10°.6					
"	5	76.5	.499	90.1		13.6					
"	6	81.3	.482	92.1		10.8	.550	84°.2	2°.9		
"	7	86.4	.452	95.5		9.1					
"	8	91.3	.423	98.9		7.6					
"	9	96.7	.404	101.1		4.4					
"	11	108.4	.332	109.6		1.2					
"	12	114.0	.340	108.6		−5.4					
Feb.	5	105.0	.342	108.4		3.4					
"	6	101.9	.348	107.6		5.7					
"	7	98.8	.372	104.8		6.0					
"	8	96.0	.368	105.3		9.3					
"	9	93.3	.396	102.0		8.7	.439	94.4	1.1		
"	12	85.8	.472	93.2		7.4					
"	13	83.6	.492	90.9		7.3	.560	83.1	−0.5		
"	14	81.5	.507	89.2		7.7					
"	15	79.4	.529	86.7		7.3					
"	16	77.4	.547	84.6		7.2					
"	17	75.6	.534	86.1		10.5					
"	18	73.8	.549	84.3		10.5					
"	19	72.1	.542	85.2	15°.2	13.1	.588	79.8	7.7	9°.9	Testudo regio at edge, 1 drawing.
"	20	70.5	.538	85.7		15.2	.593	79.3	8.8		
"	21	68.7	.545	84.8		16.1	.636	74.2	5.5		
"	22	67.3	.550	84.2		16.9	.606	77.8	10.5		" "
"	23	65.7	.574	81.5		15.8	.629	75.1	9.2		" "
"	24	64.3	.617	76.5		12.2	.609	77.4	13.1		
"	25	63.0	.612	77.1		14.1					" "
"	26	61.5	.597	78.8		17.3					
"	28	58.8	.634	74.5		15.7	.645	73.1	14.3		" "
Mar.	1	57.4	.660	71.3		13.9	.634	74.5	17.1		
"	2	56.1	.672	69.8		13.7					Partly gone.
"	3	54.8	.702	66.2		11.4					Wholly gone.
"	4	53.5	.722	63.7		10.2	.661	71.2	17.7		
"	4	53.5	.722				.677	69.3	15.8		
"	5	52.2	.770	56.1	4°.2	3.9	.683	68.5	16.3	15°.8	
"	6	50.8	.767	57.7		6.9	.709	65.3	14.5		
"	8	48.2	.792	54.2		6.	.729	62.7	14.5		
"	8	48.2	.792	54.2		6.	.744	60.8	12.6		
"	9	46.9	.810	51.7		4.8	.722	63.6	16.7		
"	9	46.9	.810	51.7		4.8	.759	58.8	11.9		
"	10	45.6	.823	49.8		4.2	.720	63.8	18.2		
"	10	45.6	.823	49.8		4.2	.739	61.4	15.8		
"	11	44.2	.834	48.1		3.9	.739	61.4	17.2		
"	12	42.7	.850	45.6		2.9					
"	14	39.7	.853	45.1		5.4					
"	15	38.2	.867	42.9		4.7					

1897. Date. G. M. N.	Phase Angle Theoretic.	Drawings: Ratio Equat. to Polar Diameters.	Phase Angle of Drawings.	Diff. between Theoretic and Drawn Phase.		Mic. Meas. Ratio Equat. to Polar Diams. both cor. for Threads only, and Polars graded from 6″.98 to 7″.69.	Phase Angle of Micrometric Measures.	Diff. between Theoretic and Measured Phase.		Remarks.
Mar. 17	35.3°	.880	40.5°	4.2°	5.2°	.757	59.1°	23.8°	15.8°	
“ 18	33.6	.915	33.9		0.3					
“ 19	31.9	.900	36.9		5.	.858	44.2	12.3		
“ 20	30.1	.930	30.7		0.6	.872	41.9	11.8		
“ 21	28.2	.912	34.5		6.3					
“ 22	26.4	.920	32.9		6.5					
“ 23	24.6	.950	25.8		1.2	.864	43.3	18.7		
“ 23	24.6	.950	25.8		1.2	.878	40.9	16.3		
“ 26	18.3	.967	20.9	4.4	2.6	.921	32.7	14.4		
“ 27	15.9	.965	21.6		5.7					
“ 28	13.6	.973	18.9		5.3					

Even before discussing them it is evident at a glance that the drawings are as accurate as the measures. This is a point worth noting, because of a very general but quite unfounded prejudice towards pinning one's faith to measures. As a matter of fact both measures and drawings depend upon eye estimates, and which of the two is the more trustworthy is a question of the kind of estimate involved.

32. **Previously received Diameters too Small.** — The measures to be discussed first are the micrometric ones of the polar diameters; and the first result indicated by them is that the hitherto received value of the planet's diameter is apparently much too small. Instead of giving the value 6″.68 for the diameter at distance unity, the measures make the polar diameter at that distance, after all correction had been taken into account, 7″.54.

33. **Explanation of it.** — Not only do the measures state this definitely, but they produce internal evidence to account for the smallness of previous determinations. They do this in what may seem an unexpected manner.

Measures of Mercury have to be made, either (1) upon the planet in transit, or (2) upon the planet as affected by phase, inasmuch as we cannot see through the Sun.

Now the present measures show that in both these cases the planet necessarily appears smaller than it is: in the first case, through irradiation; in the second, through relative invisibility of the cusps. With regard to the irradiation, the consequent loss of apparent size at transit speaks for itself; the present measures have, however, something to say about its amount, as we shall see presently. With regard to the loss of size through relative invisibility of the cusps, the measures established three points: (1) in poor seeing the measures decreased; (2) when the cusps were estimated, however slightly, the measures dwindled till they were actually smaller than previous determinations; (3) as the planet passed from quadrature toward conjunction, the measures of the polar diameters (reduced to distance unity) steadily increased. The first of these facts was testified to, *passim*. As an instance we may take the observations of March 2d and 3d.

TABLE VII.

Date.	G. M. T. Hour.	Uncor. Irr.	Corrected and Reduced to Distance Unity.	
		″	″	
Mar. 2	3.4	6.59	7.28	Seeing growing poorer.
" "	3.9	6.54	7.23	
" "	4.3	6.41	7.08	
Mar. 3	3.7	6.81	7.62	Seeing growing poorer.
" "	4.0	6.47	7.21	
" "	4.7	6.14	6.83	

We see how the decrease in the measures kept step with the decrease in the definition.

The second point is interesting because apparently conclusive. For in the day air of almost all observatories where previous determinations have been made, estimation to a greater or less extent is inevitable. So that in this case the conditions at Flagstaff were assimilated to those of other places. This is shown in Table VIII.

TABLE VIII.

Date.	G. M. T. Hour.	Uncor.	Cor. for Irr. Mic. Th. and Spu. Disk.	Reduced to Dist. Unity.	Uncor. reduced to Dist. Unity.
		″	″	″	″
Feb. 18	6.9	6.26	6.11	6.20	6.28
" 19	6.3	6.53	6.37	6.55	6.65
" 20	5.6	6.39	6.23	6.50	6.70
" 21	5.7	6.35	6.19	6.55	6.64
" 22	5.2	6.04	5.89	6.31	6.40
" 23	5.3	6.23	6.05	6.57	6.69
" 24	5.2	5.78	5.60	6.15	6.28
				6.40	6.52

The third point we see at once on taking the means of the polars for successive dates and arranging them in a table as follows.

TABLE IX.

MEANS OF POLAR DIAMETERS.

Date.	Reduced to Dist. Unity. Cor. only for Threads and Spurious Disk.	Reduced to Dist. Unity. Cor. for Irr.
	"	"
Feb. 9	6.93	6.87
Jan. 6 Feb. 13–25	7.10	7.01
Feb. 25–Mar. 1	7.20	7.06
Mar. 2–10	7.35	7.18
" 11–20	7.52	7.30
" 21–26	7.67	7.41

34. **Value of Polar Diameter.** — Taking now Table IX. and extending it to its proportionate result at conjunction, we have for the polar diameter the following values: —

Uncorrected for irradiation, 7″.80.
Corrected for irradiation, 7″.54.

These measures give for the planet a polar diameter of about 3,400 miles.

35. **Dichotomy.** — We now come to another explanation the measures afford upon quite a different subject, namely, the retardation of the apparent time of dichotomy. During the period covered by the observations dichotomy occurred four times (Washington mean time); namely, on

1896, September 11, 0 h. about.
" October 25, " "
1897, January 5, 2 h.
" February 13, 14 h.

while dichotomy should have occurred on

1896, September 16, 20 h.
" October 22, 8 h.
1897, January 8, 1 h.
" February 10, 12 h.

The discordance between the calculated and observed times of the phenomenon was therefore: —

5 days 20 h.
2 days 16 h.
2 days 23 h.
3 days 2 h.

and the mean: — 3 days 4 h.

To translate these times of retardation into phase angles of loss, we may have recourse (1) to the calculated phase; (2) to the phase loss of the drawings at the time. Thus obtained, the phase loss at these times respectively was: —

(1) °	Wt.	(2) °	Wt.
11.0	1	11	1
18.7	1	13	2
13.6	4	14	4
7.6	3	7	3

and the means, (1) 11°.9 (2) 11.°4

From the measures of the drawings we find further that the observed phase loss at the times of theoretic dichotomy at these four elongations was respectively: —

	°	Wt.
September 16,	9.6	1
October 22,	13.7	1
January 8,	8.1	1
February 10,	8.0	1

Giving a mean of 9°.9.

36. **Explanation of it.** — The cause of the discordance between the apparent and theoretic times of dichotomy has not hitherto been satisfactorily explained. Discussion of Table IX. will, I think, betray its cause.

If the centre of the terminator and its extremities lost equally in phase through inability in the eye to detect the oblique illumination out to its theoretic limit, no discordance between the observed and calculated times of dichotomy could, in the case of a sphere, ensue; in the case of an ellipsoid, there would be a difference between the observed and the calculated times of dichotomy, but as observed dichotomy would be just as likely, in the long run, to occur on the one side as on the other, the discrepancy would in the mean be zero, whereas the discordance observed is always on the same side of its theoretic value, being behind time when the phase is increasing, and ahead of it when it is decreasing. This proves, then, that the discrepancy is due to a relative visibility or non-visibility of the cusps, as compared with the centre of the terminator.

Now, if the illumination at the cusps was relatively less than that at the terminator, dichotomy would occur before its predicted time, as a geometrical consideration will show. We are therefore left with the alternative; namely, that retardation of dichotomy is due to relative prolongation of the cusps. And this can easily be shown geometrically to be the fact, as in the following diagram, where *A B*, Fig. 1, and *B C*, Figs. 2 and 3, represent the loss at their respective phases.

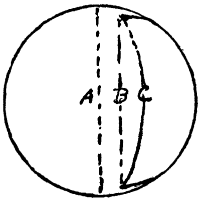


Fig. I.

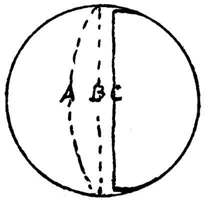


Fig. II.

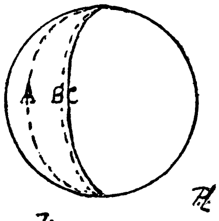


Fig. III.

37. **Loss at the Cusps.** — On the other hand, it is evident that there is some loss of visibility at the cusps. This is evident, both theoretically — otherwise there would be no loss at the centre of the terminator, since the cusps cannot be infinitely brighter than the centre — and practically, as it is witnessed to by the measures of the polar diameter, which (Table IX.) show an increase steadily from the time of dichotomy to the time of conjunction.

38. **Cusp Loss varies with Phase.** — The relative loss at the cusps is not constant. It varies with the phase. This is shown by the following table.

TABLE X.

RATIO OF EQUATORIAL TO POLAR DIAMETER, FROM DRAWINGS AND DIFFERENCE OF OBSERVED AND THEORETIC PHASE.

G. M. T. Date.	Ratio Equat. to Polar Diam. from Drawings.	Observed Phase Angle.	Theoretic Phase Angle. ι	Difference between Observed and Theoretic Phase.
Sept. 13	.510	91°.6	80°	11°.6 (?) only one.
‘‘ 14	.549	84.4	82.	2.4 poor (?) only one.
‘‘ 19	.377	104.2	96.	8.2
‘‘ 23	.299	113.7	107.	6.7
‘‘ 25	.291	114.7	114.3	.4 only one
‘‘ 26	.245	120.7	118.	2.7
‘‘ 29	.188	129.6	129.	—0.4
Oct. 16	.183	129.4	127.	2.4
‘‘ 17	.239	121.5	120.1	1.4 poor (?
‘‘ 18	.241	121.2	114.	7.2
‘‘ 19	.250	120.0	108.	12.0
‘‘ 20	.300	113.6	102.	11.6
‘‘ 24	.445	96.3	81.	15.3 { very good, examined carefully.
‘‘ 25	.535	86.0	76.1	9.9 only one.
‘‘ 28	.532	86.3	64.	22.3
‘‘ 29	.595	79.0	60.	19.0
‘‘ 30	.648	72.8	56.	16.8

39. **Amount of Loss.** — **Drawings.**—To discover what the absolute loss at the cusps is, we may begin by considering the case of the drawings. There we found (Art. 35) that the difference of phase loss at the centre of the terminator between the time of theoretic and observed dichotomy was 11°.9 — 9°.9, or 2°.0. Now Article 21 shows that the limb at the equator is brightest at the time of dichotomy, and Article 38 that the loss at the cusps decreases from a maximum at inferior to a minimum at superior conjunction. Both of these factors affect the phase deduced from the measures, but only the latter affects that shown by the drawings, as in their

case the phase is obtained by noting deviation from a straight line joining the apparent cusps. We see, then, that in the case of the drawings we have a differential catching up in the visibility of the cusps between theoretic and observed dichotomy of 2°. This shows again that there is a loss, but does not state its amount at either time.

40. **Amount of Loss. — Measures.** — For the loss in the case of the measures we may proceed as follows. The loss of visibility at the centre of the terminator, except when the libratory swing brings dark markings upon it, must be constant. Now it appears from Table XI. that, after making all corrections for irradiation — and inspection will show that no conceivably possible amount of correction will further materially affect the result — there is a difference of 10° between the phase loss at and near dichotomy and later on. This then would mark the loss at the cusps, other things being equal. The mean taken later on was carefully taken between dates when the centre of the terminator was as free as possible from the presence of dark markings. It must, however, be noticed (see the map) that the terminator crossed at the later period a much darker region than was the case at the time of dichotomy.

On the other hand, it is to be remembered that at most observatories the phase loss would be much greater, owing to poorer air. So that we may take provisionally 10° for the phase loss of the usual observations of Mercury.

41. **Discrepancy in Mercury's Right Ascension accounted for.** — Now the loss of the cusps and the increased value for the diameter explain a discrepancy in the right ascensions of the planet, noticed by Newcomb and published in his Astronomical Constants. He there says: —

"The reduction of the semidiameter of the planets was a point to which special attention was given. In the case of Mercury, the adopted semidiameter at distance unity was 3″.34. . . . When the published Right Ascension was that of the centre of light simply, a reduction to the true centre was computed by the empirical formula used in Washington observations. . . . It was assumed that when the illumination was such that the thickness of the crescent approached zero, the point observed would be two thirds of the way from the centre of the planet to the limb, and that when the planet was dichotomized the centre of observation would be five twelfths of the way from the centre to the limb. . . . The value of $\delta r''$ therefore indicates that there is a remarkable systematic difference in the observed Right Ascension according as the planet is east or west of the Sun, and therefore according to the illuminated side. The sign of the result shows that the reduction to the centre of the planet was apparently too small. . . . The most natural conclusion is that the reduction from the limb of the planet or the observed centre of light, to the true centre was too small by an amount which, at the mean distance of the Sun, must have been nearly or quite a second of arc (cf. § 3). The adopted semidiameter 3″.4 seems so well established, both by micrometric measures and by heliometer measures during transits of Mercury, that such a correction to the diameter seems inadmissible."

Now if we employ the data given by the measures I have just discussed instead of those of previous ones, we shall see that the discrepancy he noticed in Mercury's right ascension is accounted for.

Taking the hitherto received value for the diameter and applying his formula, we get five twelfths of 3″.34, or 1″.39, for the correction from the centre of light to the centre of the disk at the time of dichotomy.

Now from the present study of the planet we see, first, that at the time of theoretic dichotomy there is a loss in addition to the phase loss along the terminator due to the loss of the cusps (Art. 37), and that this amounts to 10°. This loss is represented by *A B* in Fig. 1 of the diagram in Article 36.

It is the sine of 10° into 3″.77, or 0″.65.

This is the first part of the correction; there is a second. Subtracting 0″.65 from 3″.77, we get 3″.12 for the diameter of the disk actually seen. Now at the time of theoretic dichotomy this disk was not a half-moon, as theory supposes, but a crescent, of which the centre of light by Newcomb's formula would lie in consequence not five twelfths of the way, but about half way to the limb. Dividing therefore 3″.12 by 2, we get 1″.56 for the second part of the correction, which, added to 0″.65, makes 2″.21 for the whole correction from the new data. The difference of the two determinations for the correction from the centre of light to the centre of the disk is 2″.21, less 1″.39, or 0″.82. Now 0″.82 is very nearly the discrepancy to be accounted for.

42. **General Discussion of Measures.** — We shall now proceed to a general discussion of the measures; beginning by taking up Table VI., and then Tables IX. and XII. In Table VI. is given the ratio of the equatorial to the polar diameter, first as observed in the drawings, and secondly as measured micrometrically, uncorrected; in Table XI. the ratio between the same diameters of the micrometer measures for different irradiation corrections at and near the time of dichotomy; in Table XII. the ratios of the micrometric measures of the uncorrected equatorial to the uncorrected polar at superior conjunction, that is, the true uncorrected polar.

If we study the columns of the various phase ratios, angles, and differences, we shall become aware of some curious results.

43. **Effect of Testudo regio.**—To begin with, we must note that the only extrinsic or predicable cause for variation in the differences from top to bottom is to be found in the notes at the side. At the times there specified the long dark region called Testudo regio was in the act of passing over the terminator in consequence of the libration. And this happened presumably a little earlier for the measures than it did for the drawings, first, because the eye can see better when not hampered by wires near the object observed, and can therefore in the case of the terminator see a little farther out into the decreasing illumination; and secondly, because in taking the measures a somewhat higher power was used, 167 as against 140.

This is the only cause for variation which we can eliminate from the discussion by taking account of it at the start.

44. **Increase of Visibility of the Cusps.**—Considering now the respective columns of the differences of the drawings and the measures as compared with the theoretic phase, we see that the differences agree in being, both sets of them, small at and near dichotomy, then in increasing, and then in decreasing slightly again to conjunction. The increase, which for the measures culminates about March 3, is in part due to the passing of Testudo regio across the terminator. Eliminating its effect, we find a fairly steady increase starting from the time when the phase was greatest up to the time that foreshortening began to work, on approaching superior conjunction. The general cause underlying this was the increase of visibility in the cusps of the polar diameters already considered in Article 33. How definite a factor it is, is seen more clearly yet by continuing on to an even greater phase, where from its nature it became more marked. We cannot do this with the measures because of having none, but fortunately we can do it with the measures of the drawings; and this is shown in Table X.

45. **Foreshortening due to Irradiation.**—Lastly, we perceive what we should expect to find, a falling off of the differences as we approach conjunction, owing to the increase of irradiation at the terminator due to foreshortening, an apparent increase which the increase in the polar diameter is not able to overcome.

In the following ratios the polar diameter is also corrected for irradiation, a correction amounting to twice $0''.13$, or to $0''.26$, at conjunction, making it $7''.54$. The value $7''.50$ is used throughout.

TABLE XI.

RATIO OF EQUATORIAL TO POLAR DIAMETER, FROM THE MICROMETRIC MEASURES CORRECTED FOR IRRADIATION TO THREE DIFFERENT EXTENTS.

1897. Date. G. M. N.		Cor. Irr. to 0″.13 throughout.					Cor. Irr. graded to 0″.20 at Dichot.			Cor. Irr. graded to 0″.26 at Dichot.			
			°	°				°	°		°	°	
Jan.	6	.498	90.2	8.9			.488	91.4	10.1	.482	92.1	10.8	Mean 9°.0
Feb.	9	.394	102.2	8.9			.386	103.2	9.9	.382	103.6	10.3	
"	13	.509	89.0	5.4			.500	90.0	6.4	.492	90.9	7.3	
"	19	.539	85.5	13.4			.532	86.3	14.2	.528	86.8	14.7	
"	20	.545	84.8	14.3			.538	85.6	15.1	.534	86.1	15.6	
"	21	.587	80.0	11.3			.580	80.8	12.1	.577	81.1	12.4	
"	22	.558	83.3	15.6			.551	84.1	16.8	.548	84.5	17.2	
"	23	.582	80.6	14.9			.577	81.2	15.5	.573	81.6	15.9	
"	24	.562	82.9	18.6			.557	83.5	19.2	.548	84.5	20.2	
"	28	.599	78.6	19.8			.596	78.9	20.1	.596	78.9	20.1	
Mar.	1	.590	79.6	22.2			.587	80.0	22.6	.587	80.0	22.6	
"	4	.622	75.9	22.2	21°.3								
"	4	.638	74.0	20.5									
"	5	.645	73.1	20.9									
"	6	.672	69.9	19.1									
"	8	.694	67.2	19.0	18°	Mean 19°.0							
"	8	.709	65.3	17.1									
"	9	.690	67.7	20.8	18°.4								
"	9	.727	63.0	16.1									
"	10	.688	67.9	22.3	21°.0								
"	10	.708	65.4	19.8									
"	11	.710	65.2	21.0									
"	17	.739	61.4	26.1									
"	19	.843	46.7	14.8									
"	20	.859	44.1	14.0									
"	23	.857	44.4	19.8	18°.7								
"	23	.871	42.1	17.5									
"	26	.921	32.7	14.4									

43. **Differences between Drawings and Micrometric Measures.** — The above are the points in which the two sets of measures, those by the micrometer and those from the drawings, agree. We now come to others, more interesting points, those in which they disagree. To understand them we must first consider with what the two kinds of measures are concerned. The measures of the drawings differ essentially from those of the micrometer in that the drawings are concerned solely with the apparent phase, while the micrometric measures are not concerned with the phase as such at all, but solely with the sizes of the apparent equatorial and polar diameters. from the ratio of which the phase follows as a resulting corollary. We may note in continuance that not only are the drawings directly interested in the determination of the phase, but that near dichotomy the drawings have a comparatively easy question to determine: simply the question of whether the terminator be a straight line

TABLE XII.

RATIO OF MICROMETRIC MEASUREMENT OF EQUATORIAL DIAMETER TO POLAR MERCURY WITH THREAD CORRECTIONS ONLY.

1897. Date. G. M. N.	Value of Measured Polar Diameter at Date.	Phase Angle Theoretic.	Mic. Meas. Ratio Equat. to Polar Diam.	Phase Angle of Mic. Measures.	Diff. between Theoretic and Mic. Measured Phase.		Mic. Meas. Ratio Equat. to Polar Diam.*	Phase Angle of Mic. Measures.	Diff. between Theoretic and Measured Phase.	
	″	°		°	°			°	°	
Jan. 6	7.06	81.3	.548	84.5	3.2	°	.496	90.5	9.2	Mean 7°.5
Feb. 9	7.00	93.3	.438	97.8	4.5	9.5	.393	102.3	9.0	
" 13	7.06	83.6	.557	83.5	−0.1		.505	89.4	5.8	
" 19	7.10	72.1	.588	79.9	7.8	7.2	.536	85.9	13.8	13.5
" 20		70.5	.595	79.0	8.5		.542	85.2	14.7	
" 21		68.7	.639	73.9	5.2		.582	80.6	11.9	
" 22		67.3	.609	77.4	10.1	10.4	.555	83.7	16.4	16.9
" 23		65.7	.635	74.3	8.6		.578	81.0	15.3	
" 24		64.3	.614	76.8	12.5		.559	83.2	18.9	
" 28	7.21	58.8	.644	73.3	14.5	16.3	.595	79.0	20.2	21.7
Mar. 1		57.4	.635	74.3	16.9		.587	80.0	22.6	
" 4	7.31	53.3	.659	71.5	18.0		.618	76.3	22.8	
" 4		53.3	.676	69.4	15.9		.633	74.6	21.1	
" 5		52.2	.683	68.5	16.3	15.8	.640	73.7	21.5	20.1
" 6		50.8	.711	65.0	14.2		.667	70.5	19.7	
" 8	7.36	48.2	.730	62.6	14.4		.688	67.9	19.1	
" 8		48.2	.745	60.7	12.5		.703	66.0	17.8	
" 9		46.9	.725	63.3	16.4		.684	68.5	21.6	
" 9		46.9	.763	58.3	11.4		.720	63.9	17.0	
" 10	7.41	45.6	.720	63.9	18.3		.684	67.8	22.2	
" 10		45.6	.739	61.5	15.9		.702	66.2	20.6	
" 11	7.44	44.2	.738	61.6	17.4		.704	65.9	21.7	
" 17	7.52	35.3	.760	58.7	23.4		.733	62.2	26.9	
" 19	7.60	31.9	.855	44.8	12.9		.833	48.2	16.3	
" 20		30.1	.871	42.1	12.0		.848	45.9	15.8	
" 23	7.67	24.6	.860	43.9	19.3		.846	46.2	21.6	
" 23		24.6	.874	41.6	17.0		.860	43.9	19.3	
" 26		18.3	.923	32.2	13.9		.908	35.3	17.0	

* Polar taken at 7″.80 throughout.

or not. Now this is a point susceptible of some nicety, for it is not, properly speaking, an estimate at all, but a matter of direct observation. The eye is very quick to settle whether a line be curved one way or the other. So quick is it, indeed, that the determination is in truth a criterion of the seeing at the moment, that is, of the relative amount of cusp or of terminator visible.

We come now to a deduction of some interest which follows from this. Since the drawings are our best criterion for the apparent phase, and since we know that they show more both of the centre of the terminator and of the cusps than the micrometric measures, and as at the centre of the terminator the illumination is fainter than at the cusps in consequence of which the centre would lose more than the cusps on any loss of light throughout, we see at once that the micrometric measures can never, at dichotomy, show a less loss of phase than the drawings, though they may show more; in other words, that no correction for irradiation at the limb less than that necessary to reduce the equatorial diameter to such a ratio is admissible, *provided we are dealing with a sphere.*

For such a difference between the micrometric measures and the drawings is just what an ellipsoid would cause whose longest axis pointed to the Sun. Nor would such ellipticity be more directly revealed. For when the planet is in transit his greatest axis would be pointed directly at the Earth, since the Sun and the Earth at that moment are in the same line through his centre. It is only at the times mentioned above, at and near dichotomy, that the ellipticity would show itself.

47. **Spheric and Ellipsoidal Phase.** — This is not all. There is another curious fact to be found on comparing Tables I. and VI.

If an ellipsoid be illuminated by the light from a point in a principal plane containing its longest axis, and an observer be placed in that plane at an angle from the source of light, the phase shown by the ellipsoid will not in general be the same as that shown by a sphere whose diameter is one of the two shorter axes of the ellipsoid. It will only be so in the particular case where both the terminator and the observer are in the line of the minor axis of the ellipse made by the plane. In all other positions it will be greater or less than the spheric phase, according as the terminator is on one side or the other of the minor axis, provided the observer be between the line joining the tangential points on the circle and ellipse respectively and the minor axis. If we suppose the source of light to be in the third quadrant with the major axis to its left, which were the conditions in the case of Mercury in February, and call the angle a between the source of light and the major axis of the ellipse $\iota + \omega$, we see that, if

$\iota + \omega > 90°$, then the phase shown by the ellipse > than that shown by the sphere.
$\iota + \omega = 90°$, " " " " " = " " " "
$\iota + \omega < 90°$, " " " " " < " " " "

ι is the phase angle; while ω is the angle of libration.

To an observer, then, placed nearly in the line of the minor axis, the phase shown by an ellipsoid would suddenly change from being greater than that shown by a sphere to being less as $\iota + \omega$ passed through 90°. This would cause, in the case of a planet whose phase was constantly increasing, a halting or even retrogression in that phase about that time.

Now in Table I. we see that $\iota + \omega$ became 90° between February 16 and 17. Turning to Table VI. we note that between February 16 and 17 occurred a sudden halt and retrogression in the phase.

48. **Phase of Measures.** — Thirdly, it will be noticed that the micrometric measures do not keep step with this halting of the measures got from the drawings. The former keep on more evenly, are bigger than the latter up to February, and then lose. This is precisely what should happen if the planet were an ellipsoid with its longest axis at the point of mean libration; for this was all the time getting squarer to the line of sight up to February, in consequence of which the equatorial diameter would increase up to that time, thus offsetting the loss on the terminator due to that terminator's passing through the minor axis of the ellipse, which fact alone was taken account of by the drawings.

49. **Mercury probably an Ellipsoid.** — All this is interesting from being apparently but a curious concatenation of circumstances; for though there is very little doubt that Mercury is such an ellipsoid, its longest axis pointing to the Sun, its middle one being perpendicular to this in the plane of the ecliptic, and its shortest being the planet's polar axis, there is also but little doubt from theory that the difference in the diameters is much too small to be visible, even indirectly. For each of these phenomena may be otherwise explained. Article 46 is explicable by greater irradiation at the centre of the limb; Articles 47 and 48, by the passing of Testudo regio across the terminator.

50. **Summary.** — These observations, therefore, go to show that Mercury is: —

(1) A body somewhat larger than has been supposed; its polar diameter subtending at distance unity about 7″.50, equivalent to about 3,400 miles. From the difficulty of evaluating the irradiation I consider that this is probably too large, and that 3,300 miles is nearer the truth. The older measures, however, are certainly too small.

(2) Of a probable density much less than the Earth's, and according, within errors of observation, with what *a priori* principles of size and solar position would lead us to suppose;

(3) Of a probable mass, from (1) and (2), between the older and later determinations, — about $\frac{1}{20}$ of the Earth's;

(4) Rotating in 87.969 days, its orbital period. The decimal is here given because though the period of rotation may differ by a minute amount from the

orbital period, no such deviation has been observed and it is very unlikely that any exists; especially as

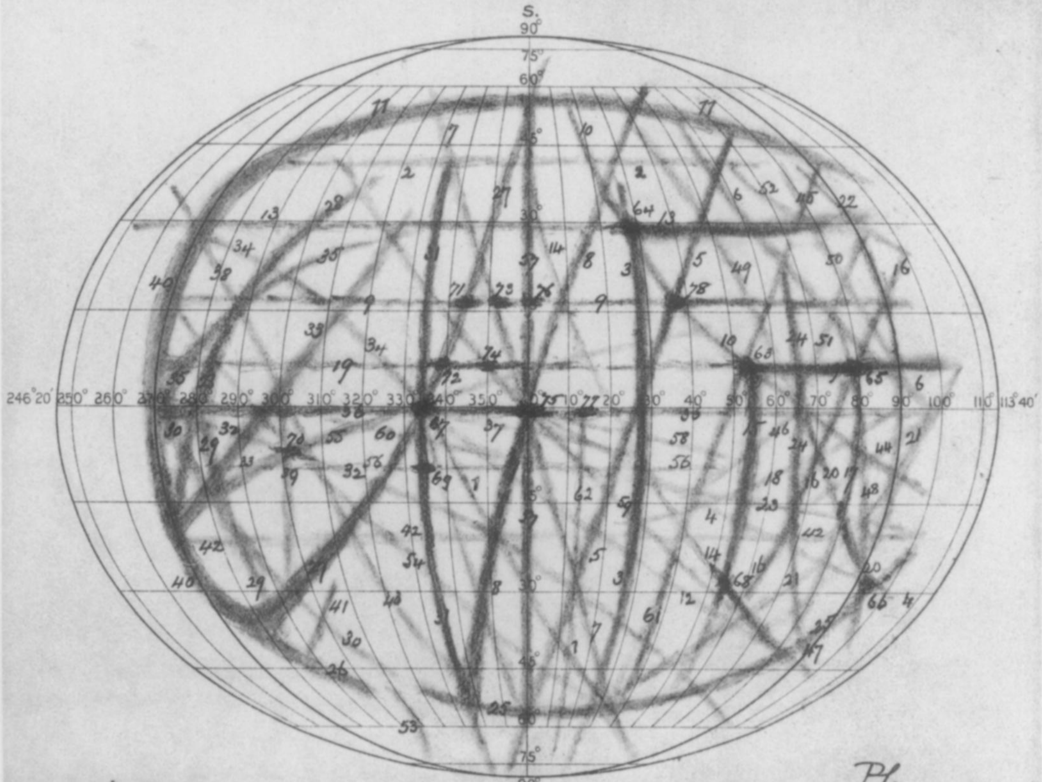
(5) There seems to be evidence that it has rotated thus from the time it was plastic;
(6) About an axis approximately perpendicular to the plane of its orbit;
(7) Possessing no certain signs of atmosphere;
(8) Nor sign of water;
(9) Nor of vegetation;
(10) Nor of organic life;
(11) Covered with long narrow markings best explained as the results of cooling;
(12) Somewhat symmetrically disposed, thus suggesting (5);
(13) A world as dead as the Moon, but differently brought to such condition.

INDEX TO PLATE XXVII.

1. Maia.
2. Hypate.
3. Zugon.
4. Thoth.
5. Oneiraton.
6. Ala.
7. Cyllene.
8. Psychopompos.
9. Lichanos.
10. Petasus.
11. Keras.
12. Agetor.
13. Parhypate.
14. Hegemonios.
15. Enodios.
16. Agoraios.
17. Caduceus.
18. Empolaios.
19. Mese.
20. Anguis.
21. Serpens.
22. Keryx.
23. Diemporos.
24. Pedilla.
25. Cornu
26. Talaria.
27. Plectron.
28. Ebur.
29. Corneus.
30. Somnus.
31. Oneiropompos.
32. Poimandres.
33. Psychagogos.
34. Trismegistos.
35. Aphorismos.
36. Paramese.
37. Kuranides.
38. Smaragdina.
39. Chlamys.
40. Testudo.
41. Pteron.
42. Paranete.
43. Nomios.
44. Dolios.
45. Lichanos.
46. Sokos.
47. Pheneos.
48. Phara.
49. Pelene.
50. Carvara.
51. Kephalos.
52. Hegemonios.
53. Vayu.
54. Turms.
55. Necropompos.
56. Trite.
57. Hermes.
58. Boukolos.
59. Kriophoros.
60. Polygios.
61. Promaxos.
62. Sarameya.
63. Mese meson.
64. Parhypate hypaton.
65. Mese hypaton.
66. Nete hypaton.
67. Paramese hypaton.
68. Nete meson.
69. Trite diezeugmenon.
70. Trite hyperbolæon.
71. Lichanos hyperbolæon.
72. Mese hyperbolæon.
73. Lichanos synemmenon.
74. Mese diezeugmenon.
75. Paramese meson.
76. Lichanos meson.
77. Paramese hypaton.
78. Lichanos hypaton.

The names have been given in accordance with the suggestion of the markings themselves whose outline is singularly like the tortoise-shell lyre invented by the god; the lines along the parallels of latitude being the strings and the conspicuous marking 29 representing the plectron.

MAP OF MERCURY

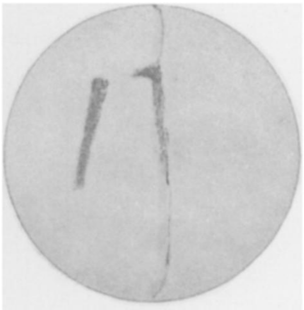


LOWELL OBSERVATORY
1896-97

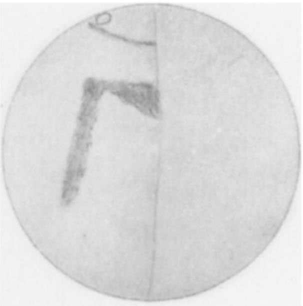
MERCURY.

MEMOIRS AMERICAN ACADEMY, VOL. XII

PLATE XXVIII.



Sept. 2—4h 32m.
$\lambda=64^\circ$.



Sept. 2—5h 40m.
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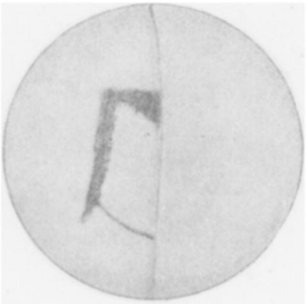
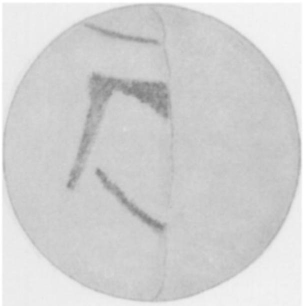
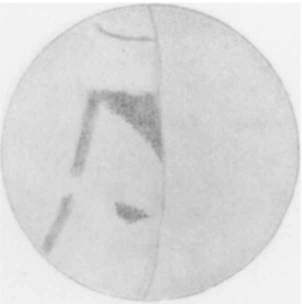


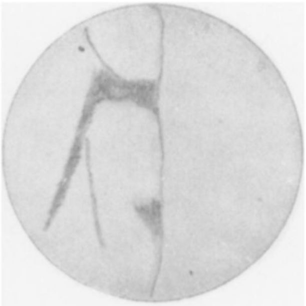
Sept. 2—5h 45m.
$\lambda=64^\circ$.



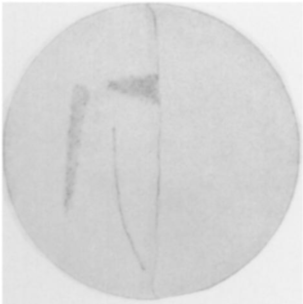
Sept. 3—4h 45m.
$\lambda=65^\circ$.



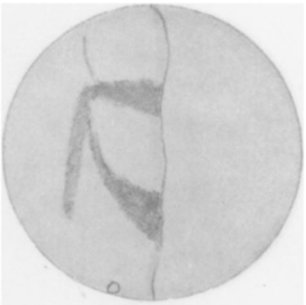
Sept. 3—5h.
$\lambda=65^\circ$.



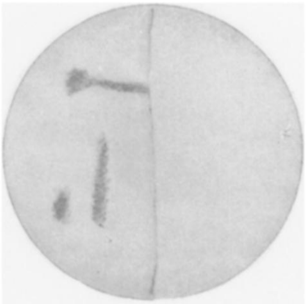
Sept. 3—5h 15m.
$\lambda=65^\circ$.



Sept. 5—5h 33m.
$\lambda=70^\circ$.



Sept. 5—5h 50m.
$\lambda=70^\circ$.

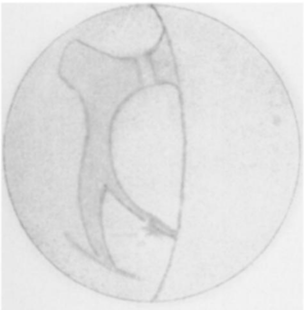


Sept. 13—5h 29m.
$\lambda=95^\circ$.

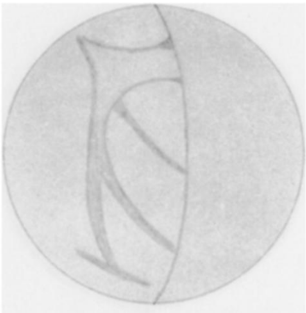
Lowell Observatory.
October 10, '96.

Drawings by Percival Lowell.

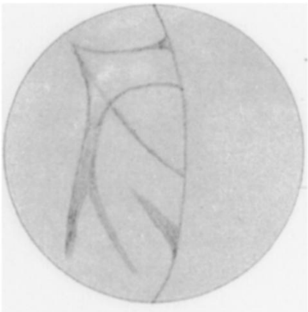
MERCURY.



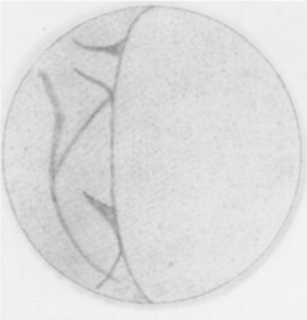
Sept. 2, '96—4h 45m.



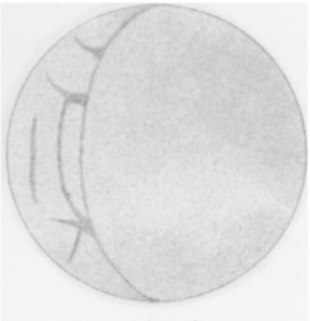
Sept. 3, '96—4h 40m.



Sept. 3, '96—5h 20m.



Sept. 23, '96—4h 30m.

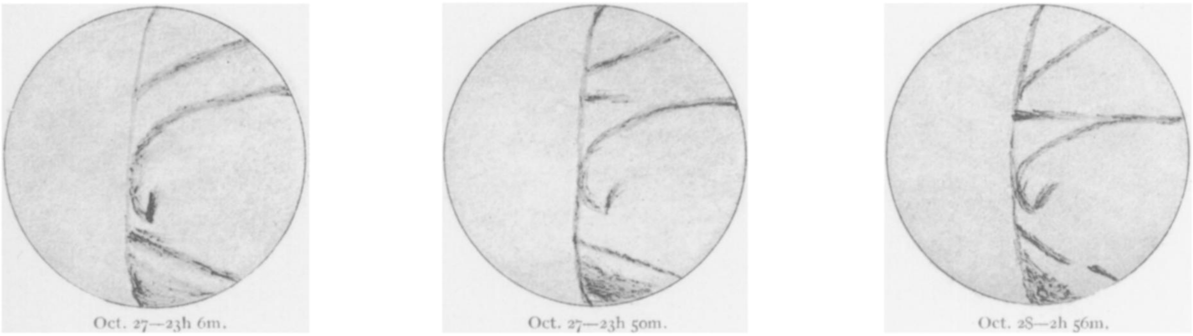


Sept. 26, '96—3h 50m.

Lowell Observatory.

Drawn by D. A. Drew.

MERCURY.

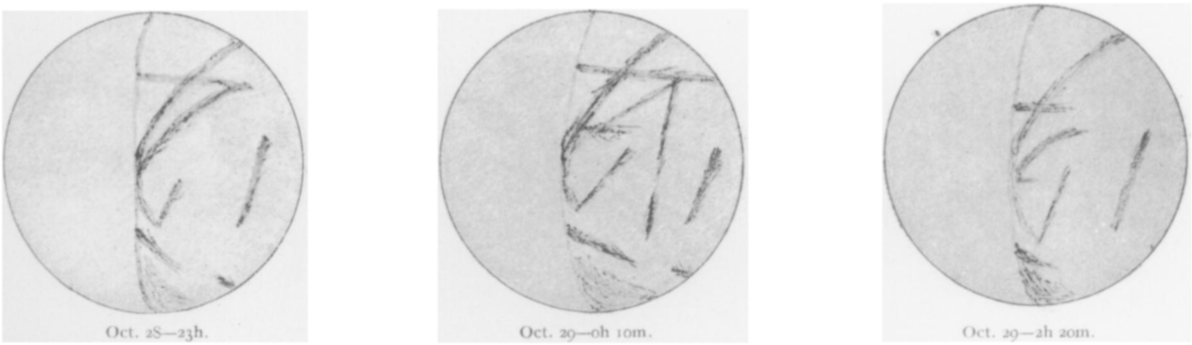


Oct. 27—23h 6m.

Oct. 27—23h 50m.

Oct. 28—2h 56m.

Triad of Drawings Oct. 27-28.

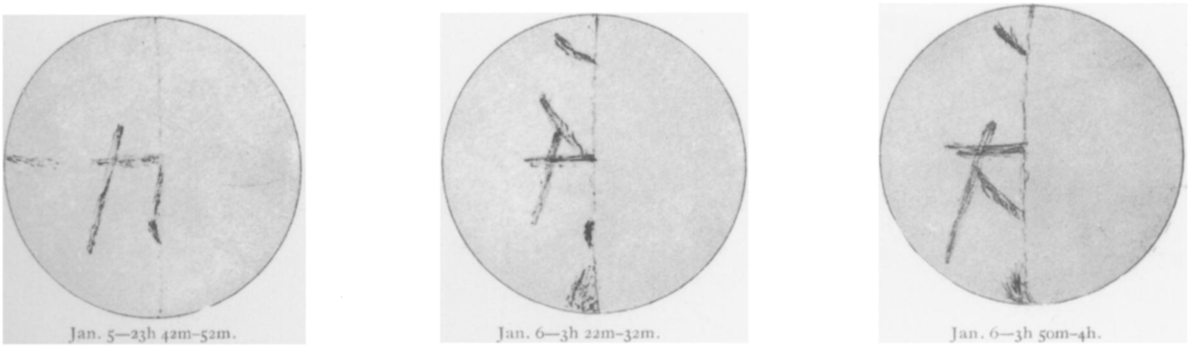


Oct. 28—23h.

Oct. 29—0h 10m.

Oct. 29—2h 20m.

Triad of Drawings Oct. 28-29.



Jan. 5—23h 42m–52m.

Jan. 6—3h 22m–32m.

Jan. 6—3h 50m–4h.

Triad of Drawings Jan. 5-6.

LOWELL OBSERVATORY.
1896-7.

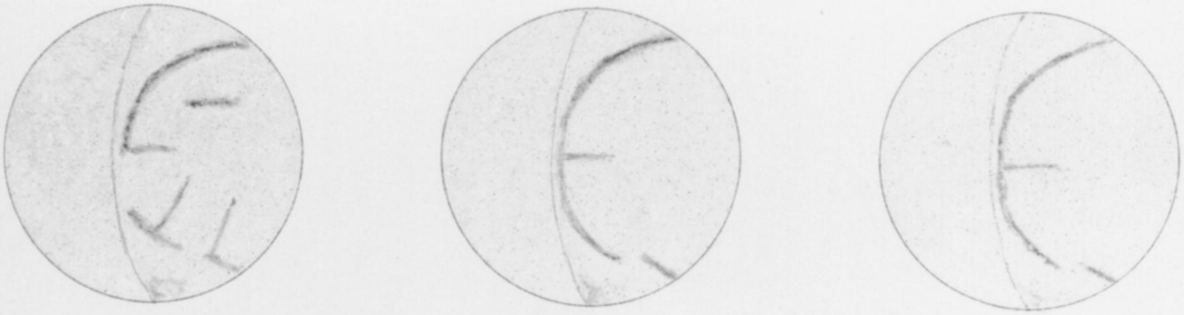
THREE TRIADS OF DRAWINGS,

SHOWING SLOW ROTATION.

DRAWINGS BY MISS LEONARD.

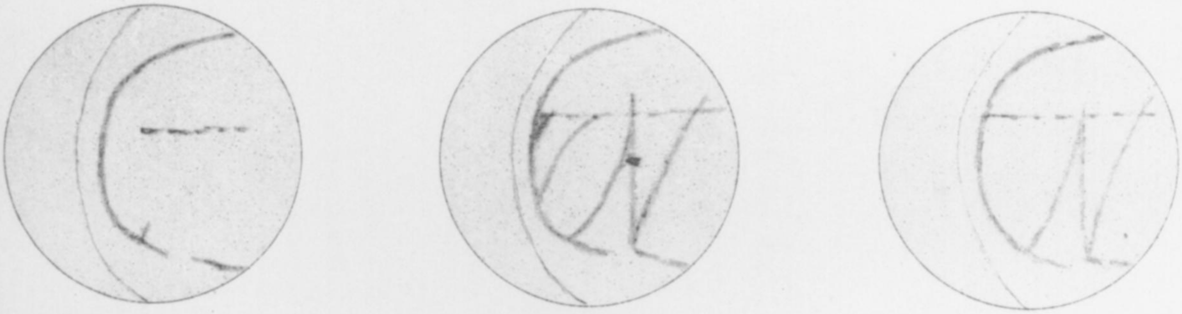
MERCURY.

MEMOIRS AMERICAN ACADEMY, VOL. XII. PLATE XXXI.



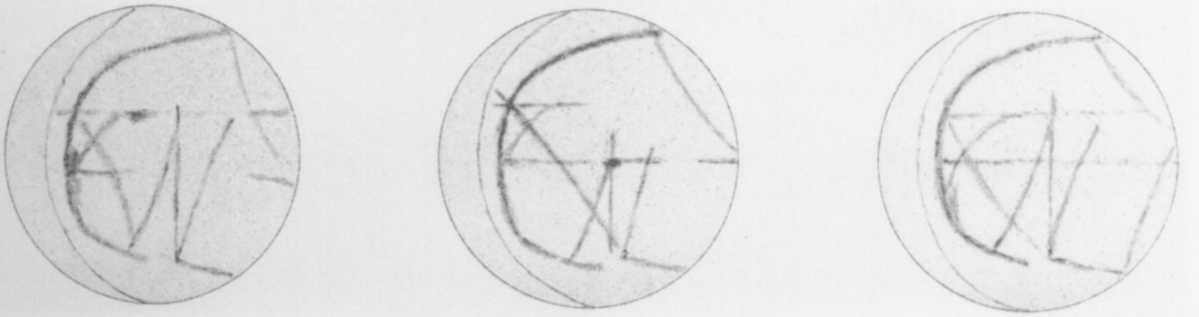
Oct. 29—22h 20 m. Oct. 29—23h 0m. Oct. 30—4h 2m.

Triad of Drawings Oct. 29-30.



Nov. 1—21h 16m. Nov. 2—0h 38m-45m. Nov. 2—2h 40m.

Triad of Drawings Nov. 1-2.



Nov. 4—22h 50m. Nov. 5—0h 11m-19m. Nov. 5—21h 39m-46m.

P. L.

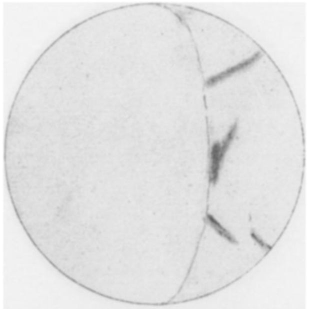
Triad of Drawings Nov. 4-5.

Lowell Observatory.
1896.

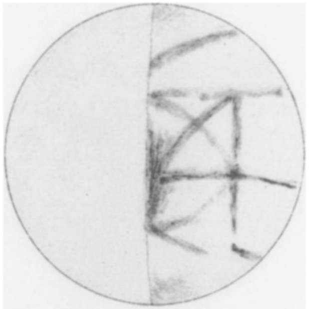
THREE TRIADS OF DRAWINGS, THREE DAYS APART

SHOWING SLOW ROTATION.

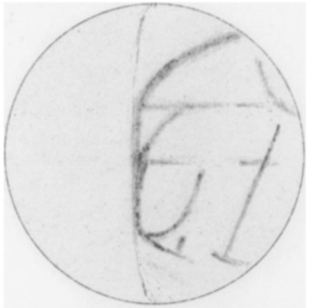
MERCURY.



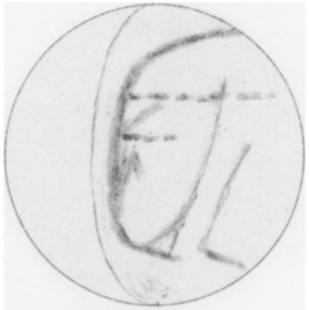
Oct. 19—23h 45m.
$\iota=102^\circ$. $\omega=-4^\circ$.



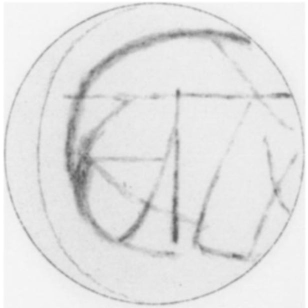
Oct. 24—23h 38m-Oct. 25—0h 4m
$\iota=76^\circ$. $\omega=-15^\circ$.



Oct. 28—22h 49m-57m.
$\iota=60^\circ$. $\omega=-20^\circ$.

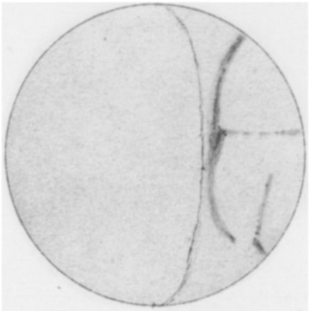


Oct. 31—23h 18m-32m.
$\iota=49^\circ$. $\omega=-23^\circ$.

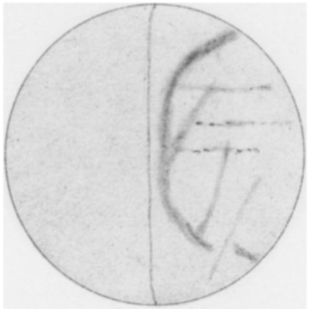


Nov. 8—22h 54m-23h 8m.
$\iota=28^\circ$. $\omega=-23^\circ$.

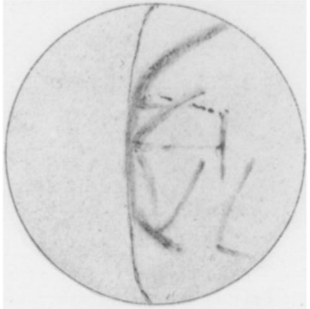
1896.



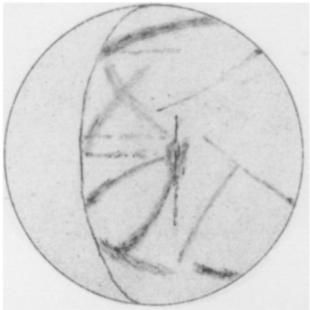
Feb. 5—23h 23m-37m.
$\iota=102^\circ$. $\omega=-22^\circ$.



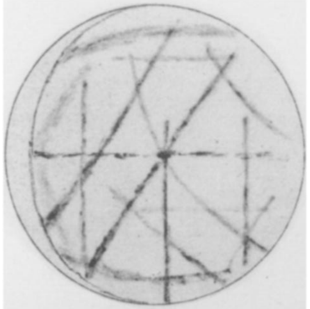
Feb. 14—21h 40m-22h 2m.
$\iota=82^\circ$. $\omega=-16^\circ$.



Feb. 27—22h 19m-28m.
$\iota=60^\circ$. $\omega=0^\circ$.



Mar. 3—20h 35m-48m.
$\iota=55^\circ$. $\omega=+5^\circ$.



Mar. 20—19h 56m-20h 14m.
$\iota=28^\circ$. $\omega=+23^\circ$.

1897.

ι =the angle between Sun and Earth at Mercury.

ω=the angle of libration.

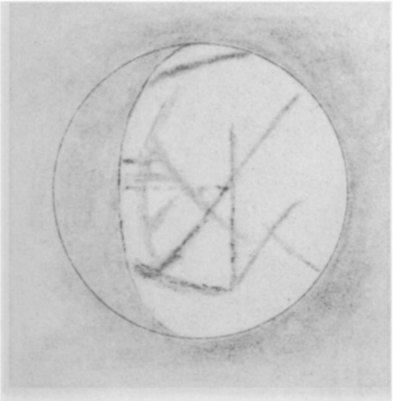
LIBRATION

DUE TO THE ECCENTRICITY OF THE PLANET'S ORBIT
MADE VISIBLE BY THE MARKINGS.

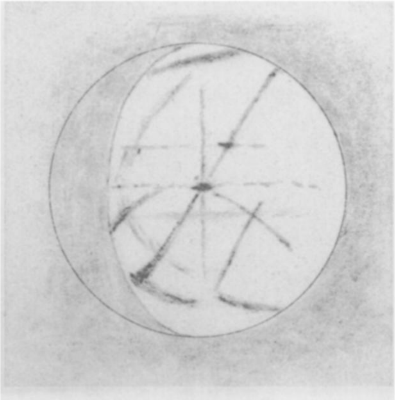
LOWELL OBSERVATORY, 1896–7.

All the Drawings are by Percival Lowell.

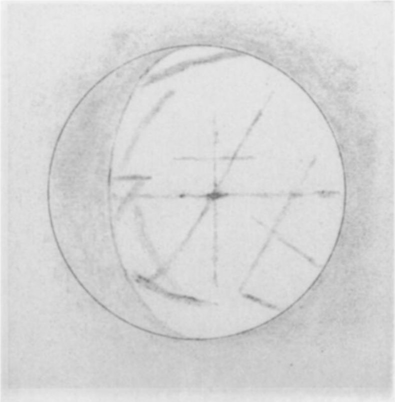
MERCURY.



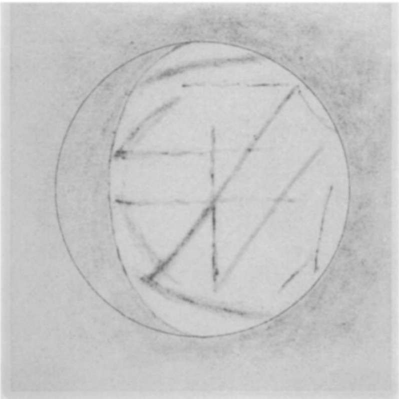
Mar. 5—20h 28m.



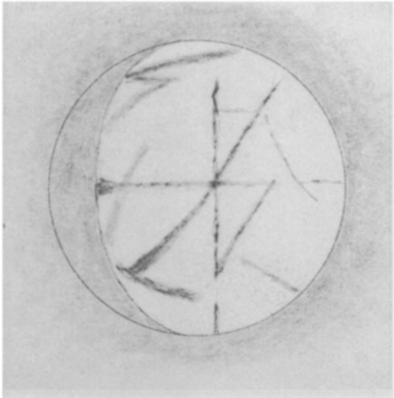
Mar. 7—20h 3m-29m.



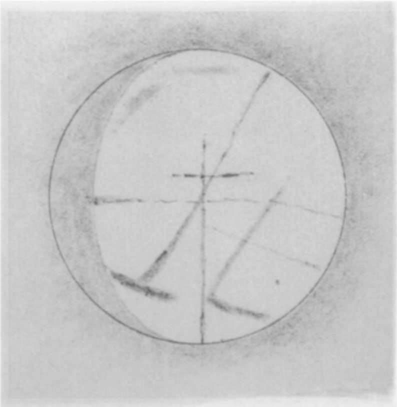
Mar. 8—21h 22m-37m.



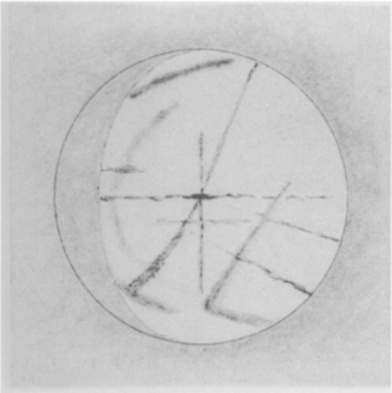
Mar. 9—19h 47m-20h 4m.



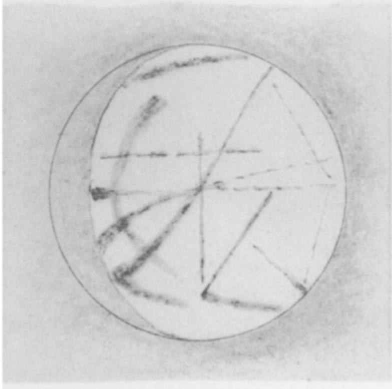
Mar. 10—19h 40m-52m.



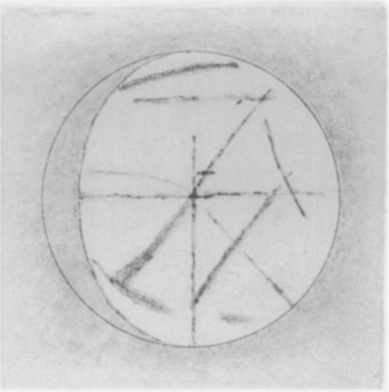
Mar. 11—20h 10m-31m.



Mar. 13—19h 36m-43m.



Mar. 14—20h 7m-17m.

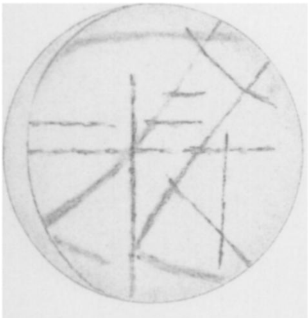


P. L.

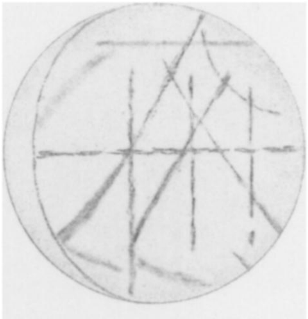
Mar. 16—19h 40m-51m.

Lowell Observatory.
Mexico, 1897.

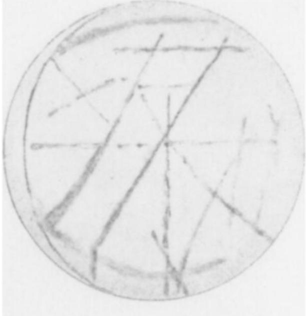
MERCURY.



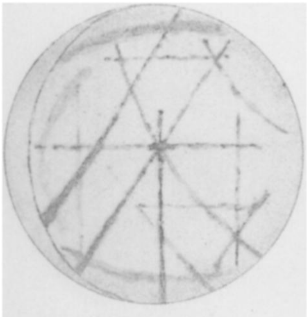
Mar. 17—19h 51m–20h 0m.



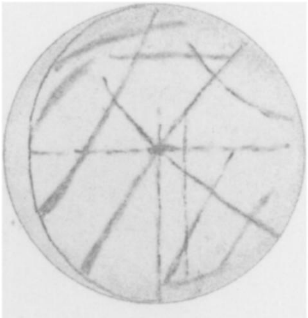
Mar. 18—19h 38m–47m.



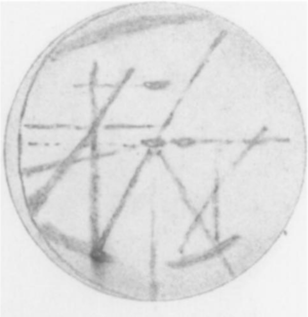
Mar. 19—20h 8m–37m.



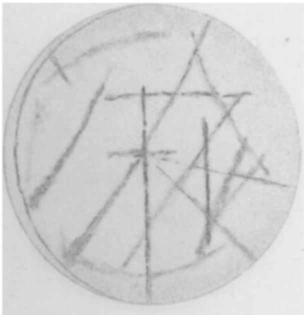
Mar. 20—19h 56m–20h 14m.



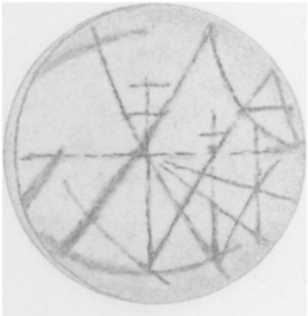
Mar. 21—20h 43m.



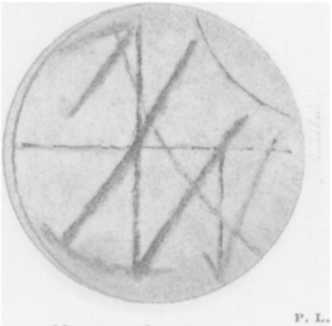
Mar. 22—20h 39m–58m.



Mar. 25—20h 7m–27m.



Mar. 26—21h 33m–56m.



Mar. 27—21h 31m–46m.

P. L.

Lowell Observatory.
Mexico, 1897.